# Swords into Plowshares and Beyond

LOOKING back 25 years at the nation's energy situation and comparing it to today's, one might be tempted to mutter, "*Déjà vu*." In the mid-1970s, the nation was in the middle of an energy crisis: oil shortages, long lines at the gas pumps, uncertainties over our energy future. Today, gasoline prices in some areas of the country are frequently over two dollars a gallon, rolling "brown-outs" are all too frequent during a hot California summer, and energy prices are rising as the deregulation of California power companies begins.

In the seventies, the first decade of Roger Batzel's nearly two-decade term as director of Lawrence Livermore, finding ways to enhance the nation's energy supply was a national priority. The year Batzel became director, Congress amended the charter of one of the Department of Energy's predecessors, the Atomic Energy Commission (AEC), to support nonnuclear energy research.

Bob Schock, who spent much of the 1970s, 1980s, and 1990s managing one aspect or another of the Laboratory's energy efforts and is now with the Center for Global Security Research, recalls: "In the 1970s, the Lab was already in the energy business through Project Plowshare, which was exploring the peaceful uses of nuclear explosions. When the energy crisis hit in 1972 and 1973, Lawrence Livermore and Oak Ridge were the two leading AEC national laboratories in energy-related research."

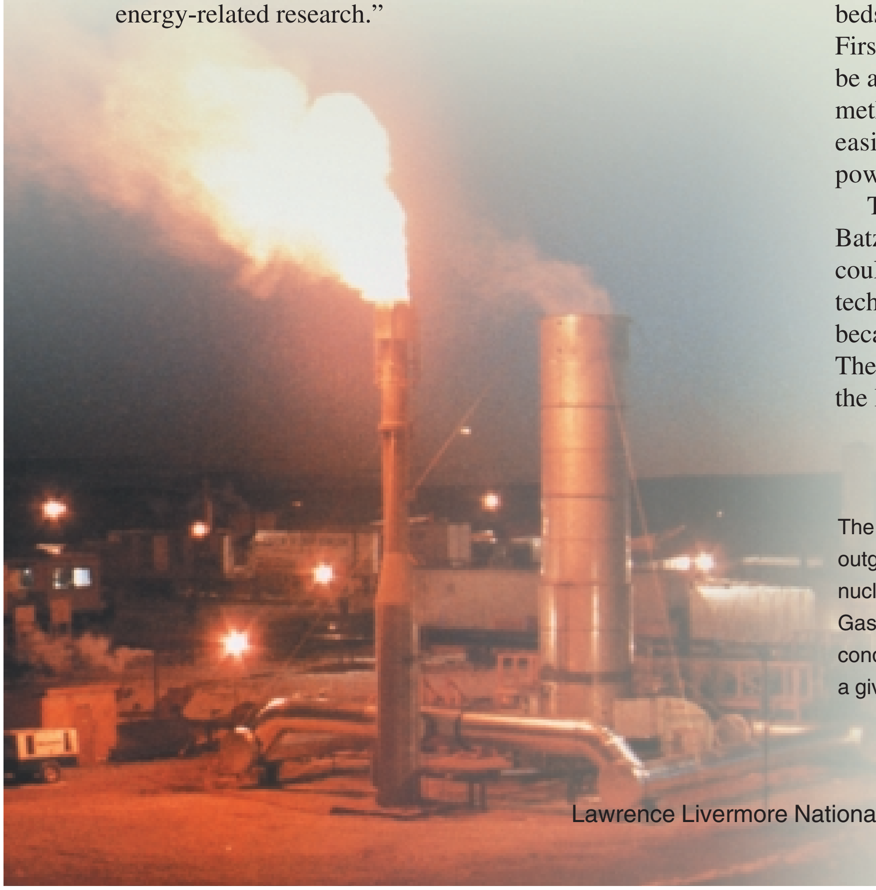
Along with Plowshare, two other large-scale energy-related efforts at the Laboratory that predated the energy crisis were laser fusion and magnetic fusion. In the 1970s, the Laboratory also became active in researching how to safely dispose of radioactive waste from nuclear power plants—an activity that continues to this day. Finally, with the country's attention turned toward alternate energy supplies, Lawrence Livermore's scientists and engineers researched energy sources such as coal, oil shale, geothermal energy, solar power, electric roadways, and advanced batteries.

## The Plowshare Energy Legacy

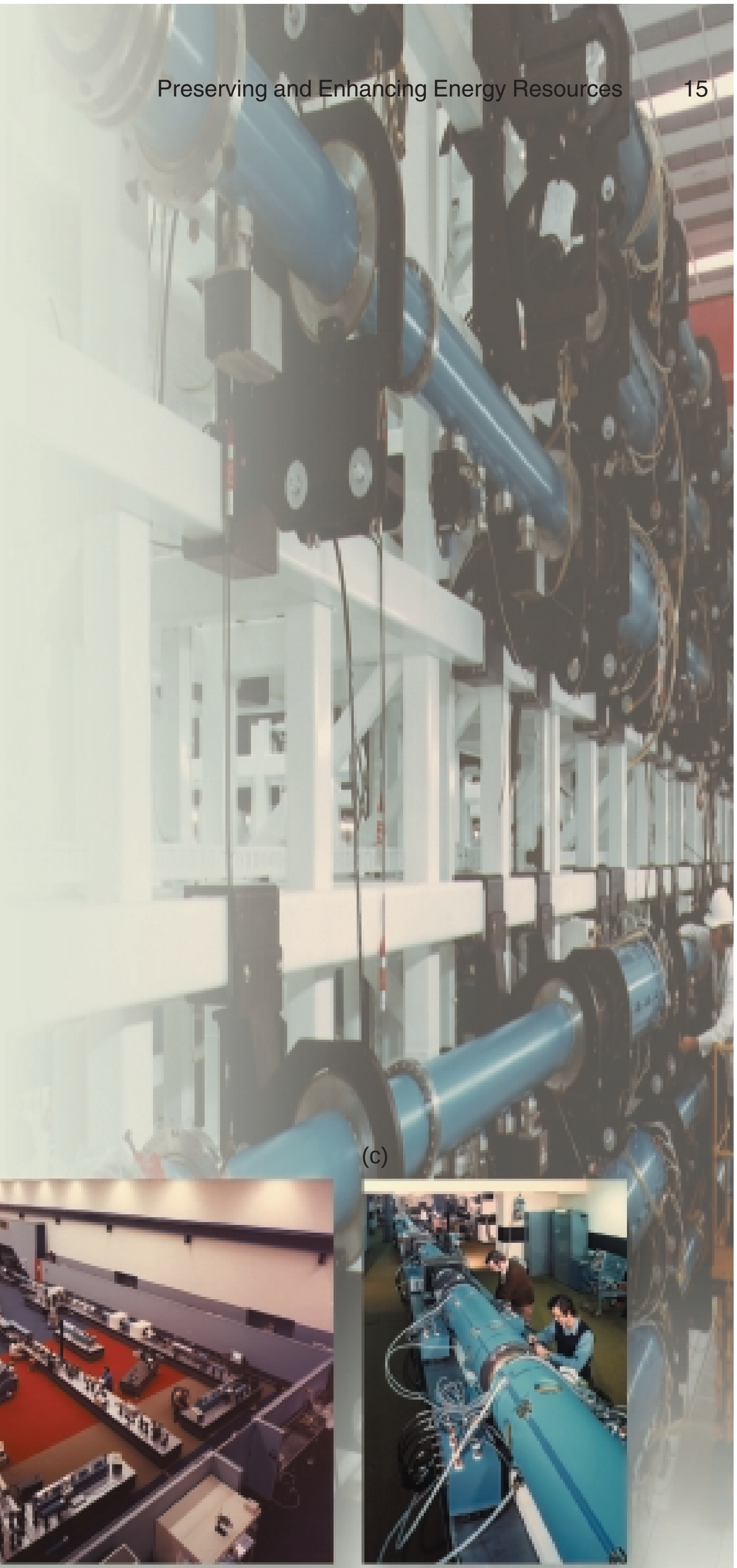
In 1957, the AEC officially established Project Plowshare to explore the use of nuclear explosives for peaceful purposes. "Plowshare had two parts," explains Schock. "There was a civil engineering component—using nuclear explosives to make canals, dams, and such—and an energy component—using nuclear explosives to stimulate natural gas reservoirs, process underground oil shale into oil, and so on." Even though Plowshare was terminated in 1977, its legacy lived on into the 1990s through energy projects in these areas and others.

From 1974 through 1988, the Laboratory developed an underground coal gasification process that converted coal beds into gas without mining. This method had two benefits. First, it reached coal that, for economic reasons, could not be accessed with the usual mining techniques. Second, the method produced a combustible gas that was easy to clean—easier, in fact, than the stack gas produced by coal-fired power plants.

This project and others, Schock notes, benefited from Batzel's belief in conducting large-scale demonstrations that could prove or disprove the commercial viability of a given technology. "Large-scale demonstrations were the Lab's forte because of our experience in nuclear testing," adds Schock. The Laboratory did some large experiments in Wyoming in the late 1970s to early 1980s to gasify coal seams in-place.



The Laboratory's research into underground coal gasification was an outgrowth of Project Plowshare, which explored the peaceful uses of nuclear explosives. The Rocky Mountain Underground Coal Gasification Test Facility in Wyoming reflected Roger Batzel's belief in conducting large-scale demonstrations to test the economic viability of a given technology.



"We started by using high explosives—we'd forgone nuclear explosives by then—and then came up with a technique that gasified the coal without explosives. It uses the natural fractures in coal and controls the burn zone through a movable oxygen injector.

"In situ coal gasification is still a good idea," says Schock. "If the technology is ever implemented, it could double or triple the accessible U.S. coal reserves and has the advantage that the carbon dioxide produced by the process can be separated out and captured."

In another Plowshare offshoot, the Laboratory investigated the feasibility of using nuclear explosives—and later, high explosives—to fracture oil shale. As Schock explains it, one can convert oil shale to oil by subjecting it to high temperatures and high pressures—in other words, by speeding up the geologic clock. Laboratory researchers envisioned using explosives to fracture the vast oil-shale reserves in the western U.S. so that the oil could be processed in place, which would provide an important alternative to imported oil. This effort evolved in the early 1980s into a surface oil-shale retorting process that used hot oil-shale particles as the heat carrier. It also produced a model of how oil is formed that is today used for exploration by every major oil company in the world.

## Lasers and Energy

Part of what drove the Laboratory's early research into lasers was the prospect of creating fusion energy as a virtually

(a) (b) (c)

A series of large laser systems developed during Batzel's term as director helped researchers gain understanding of the inertial confinement fusion process, in which small targets containing deuterium–tritium fuel are compressed using the energy of a laser beam. (a) The two-beam Janus laser (1975) was used to demonstrate laser implosion and thermonuclear burn of primitive targets. (b) The two-beam Argus (1976) increased understanding of laser–target interactions and helped researchers develop technologies for the next generation of systems. (c) The one-beam Cyclops (1975) demonstrated radiation implosion targets and tested optical designs for the Shiva laser. The 20-beam Shiva (1977), shown in the background above, was the most powerful laser at that time, delivering more than 10 kilojoules of energy in less that a billionth of a second in its first full-power firing. Thermonuclear fuel was imploded to 100 times liquid density in Shiva experiments.

inexhaustible, low-cost, safe, and environmentally attractive energy source. Laboratory researchers envisioned doing this through inertial confinement fusion (ICF), in which small targets of fuel are imploded by laser beams until the fuel reaches temperatures that induce fusion. Beginning in 1972, the Laboratory pursued this vision in a series of increasingly powerful laser systems—each five to ten times more powerful than its predecessor. Janus (completed in 1975), Shiva (1977), and Nova (1984) gave laser researchers the tools to expand scientific understanding and to take the nation a step closer to achieving the fusion process. The latest of these systems—the National Ignition Facility—will be an important component of the Department of Energy's Stockpile Stewardship Program (see related article on pp. 18–20), and will, in addition, provide the most powerful system yet for exploring the ICF energy conversion process.

Another energy-related laser effort that continued into the 1990s was the Laboratory's development and refinement of laser isotope separation (LIS) technology. Atomic vapor laser isotope separation (AVLIS) was first developed to separate uranium-235, needed to fuel fission reactors, from the common isotope uranium-238. LIS began in 1973, culminating in enrichment demonstrations in 1980. The technology was then expanded to a large-scale experiment by 1985. The success of these demonstrations led DOE to select U-AVLIS over other enrichment technologies for commercial development. Although the AVLIS program was scaled back in the late 1990s, the LIS process may find other important applications in medicine, astronomy, energy, and industry. (See *S&TR*, May 2000, pp. 13–21.)

## Magnetic Fusion Energy

Another early energy effort was research on magnetic fusion energy. This research had been part of the Laboratory since its founding in 1952 and grew under Batzel's directorship. In the magnetic confinement concept, the fuel is trapped in a magnetic force field long enough to achieve fusion. These systems use large electric currents traveling through huge magnet coils to produce the immensely strong magnetic fields needed. The Laboratory experimented with confining the fuel with giant magnets in experiments such as Levitron, Baseball I and II, TMX (Tandem Mirror Experiment), 2XIIB, and MFTF (Mirror Fusion Test Facility), culminating in the MFTF-B, initiated in 1981. The magnet system for MFTF-B was the largest superconducting system ever built. Shortly after the system was completed in 1986, DOE, faced with budget reductions, decided to focus its magnetic fusion energies on a different technology—the tokamak. The Laboratory then became a contributor to the International Thermonuclear Experimental Reactor (ITER) project to design and build the world's first full-scale magnetic fusion reactor.

More recently, Livermore fusion energy scientists are revisiting the spheromak concept. A tokamak's magnetic fields are generated by large, external magnetic coils surrounding a doughnut-shaped reactor, with other magnets in the hole in the donut. A spheromak, as Schock explains, "takes the hole out of the doughnut." In the spheromak configuration,

During Batzel's tenure as director, the Laboratory explored a number of energy options, including capturing energy from solar ponds. Researchers determined that adding a 1.8-meter reflector panel to this shallow solar pond test module increased its efficiency by about 25 percent annually.

the plasma fuel produces some of its own confining magnetic fields, requiring only an external set of coils and making for a much more compact machine capable of producing a higher-temperature and higher-density plasma. (See *S&TR*, December 1999, pp. 18–20.)

### Closing the Fuel Cycle

With nuclear fission still an important source of electric power in the United States and throughout the world, a way must be found to satisfactorily close the fuel cycle—that is, a method for safely disposing of the radioactive waste produced by nuclear power plants. Beginning in 1977, the Laboratory participated in studies of a candidate site for a U.S. high-level waste repository that culminated in the choice of the Yucca Mountain site in Nevada.

In 1987, Congress directed DOE to study the Yucca Mountain site for its feasibility as a permanent repository for high-level nuclear waste. The Laboratory was responsible for designing the waste package and barrier system for the proposed repository. As part of this responsibility, Laboratory scientists designed a computer code that would run on the world's most powerful computers and show how buried nuclear wastes would affect the Yucca Mountain geology. (See *S&TR*, March 2000, pp. 13–20.)

From 1980 to 1984, Livermore scientists and engineers also designed, built, and operated the only experiment to retrievably store commercial spent-fuel underground at the Climax Mine in Nevada. At the time, Climax was the first place in the world where high-level radioactive waste from fission reactors was stored underground for any length of time. The successful demonstration of this concept paved the way for future repositories.

One of the magnets for the Mirror Fusion Test Facility-B, the Laboratory's most ambitious magnetic mirror fusion experiment. Two pairs of these enormous magnets were needed to confine the fusion fuel plasma. Cutbacks in energy and environmental work in the 1980s caused this test facility to be mothballed shortly after its completion in 1986. However, Livermore stayed involved in magnetic fusion energy research through the International Thermonuclear Experimental Reactor and, more recently, the spheromak.

### A Plethora of Smaller Projects

Although the Laboratory had many large demonstration projects during the 1970s and 1980s, smaller energy projects also flourished. For instance, the Laboratory explored the feasibility of using shallow ponds to store solar energy to produce domestic heat and run chemical processes. And on their own, several engineers rigged up a surrey—basically a golf cart—with solar panels to test the feasibility of using solar energy in transportation.

Battery research, starting with aluminum–air batteries, was also a consequence of the Laboratory's emergence in the 1970s as a powerhouse in DOE energy research. The current incarnation of the battery research is the refuelable zinc–air fuel cell, an alternative to the standard lead–acid batteries now powering most cars and other vehicles. The fuel cell promises trouble-free, nearly 24-hour-a-day operation for numerous kinds of electric vehicles, from forklifts to delivery vans and possibly personal automobiles.

### Batzel Stood Back, Let Ideas Blossom

Batzel was well known for standing back and letting people follow their inclinations. But, as Schock is quick to point out, that didn't mean he was not aware of what was going on within the programs. "When you had a review, it was quickly apparent that he was technically on top of his game. He didn't wait for you to tell him about the technical aspects. He *knew*. He understood the details, but didn't try to run the programs, instead focusing on the big picture. He developed a tremendous number of leaders at the Laboratory. He did it with a hands-off style and didn't try to micromanage. It was a time when people, programs, and ideas blossomed, in energy research as well as throughout the Laboratory."

*—Ann Parker*

**Key Words:** battery research, Climax Mine, coal gasification, energy program, fuel cell research, International Thermonuclear Experimental Reactor (ITER), laser fusion energy, magnetic fusion energy, Mirror Fusion Test Facility-B (MFTF-B), National Ignition Facility (NIF), oil-shale retort, Project Plowshare, Roger Batzel, solar surrey, spheromak, uranium atomic vapor laser isotope separation (U-AVLIS), Yucca Mountain.

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